Compensation for the Atmosphere in Radiance Measured by the Airborne Visible/Infrared imaging Spectrometer and Applications to an Advanced Land Remote Sensing System

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ABSTRACT

The Airborne Visible/Irrfrarcrl Imaging Spectrometer measures spatial images of the total upwelling spectral radiance from 400 to 2500 nm through 10 nm spectral channels. Quantitative research and application objectives for surface investigations require conversion of the measured radiance to surface reflectance or surface leaving radiance. To calculate apparent surface reflectance an estimation of atmospheric water vapor abundance, cirrus cloud effects, surface pressure elevation and aerosol optical depth arc also required. Algorithms for the estimation of these parameters from the AVIRIS data themselves arc described. Based upon these determined atmospheric parameters wc show an example of the calculation of apparent surface reflectance from the AVIRIS-measured radiance using a radiative transfer code. Wc also propose spectra] band characteristics for an advanced land remote sensing system that would bc necessary to support these or similar atmospheric compensation algorithms.

1.() INTRODUCTION

The Airborne Visible/lnfrarcrf imaging Spectrometer (AVIRIS) is a NASA-sponsored Earth-looking imaging spectrometer designed, built and operated by 'the Jet Propulsion laboratory. AVIRIS acquires flight data from the Q-bay of a NASA ER-2 at 20 km flight altitude. AVIRIS measures the total upwelling radiance from 400" to 2500 nm in the spectrum through 224 channels at 1 0 nm spectral intervals. An example of the AVIRIS spectral coverage in comparison to that of the Thematic Mapper is given in Figure 1. Data arc acquired as 1 1 by up to 100" km images with 20 by 20 m spatial resolution. In Plate 1, the spatial characteristics of an AVIRIS image arc shown for data acquired over Mount Shasta, California. AVIRIS data arc rigorously calibrated with respect to their spectral, radio metric and geometric characteristics in [hc laboratory; these calibrations arc validated in-flight. A valid calibration is required for the physically based algorithms described.

In this paper, an AVIRIS data set acquired on the 2nd of June 1992 over a portion of the San Francisco peninsula that included the Jasper Ridge ecological preserve is used. This AVIRIS scene covers 10 by 11 km and includes a variety of vegetated and unvegetated surface cover types. Figure 2 shows an AVIRIS measured radiance spectrum for a green grass area in this scene. The shape of this spectrum results from the solar irradiance, molecular and aerosol scattering of the atmosphere, gas absorption of the atmosphere, illumination geometry and the reflectance of the surface. The algorithms presented to estimate the atmospheric characteristics and to calculate apparent surface reflectance usc the MODTRAN2 (Berk et al.. 1989) radiative transfer code in conjunction with a nonlinear least squares spectral fitting (NLLSSF) procedure.

2.0 WATER VAPOR

over most of the 400 to 2500 nm spectral range [hc strongest atmospheric absorber is water vapor, The effect on the upwelling radiance arriving at an optical sensor is shown in Figure 3. in addition to absorbing strongly in this spectral range, the abundance of water vapor in the terrestrial atmosphere varies significantly both spatially and temporally. For example, greater than 20 percent variation in the spatial and temporal distribution of water vapor has been described for four AVIRIS data sets acquired at 12 minute intervals over the same site (Green et al., 1991a).

To compensate for water vapor absorption in AVI RIS spectra, a determination of total path water vapor is required for each spatial element. Water vapor algorithms for AVIRIS have been developed (Conel et al 1988, Green et al 1989, and Green, et al. 1991a) based initially on the LOWTRAN7 (Kneizys et al., 1987) and currently on the MODTRAN2 (Berk et al., 1989) radiative transfer code. The water vapor algorithm fits the AVIRIS measured radiance for the 940 nm water band to a radiance spectrum generated by the radiative transfer code. A NLLSSF procedure is used with parameters allowing the atmospheric water vapor amount, the reflectance magnitude, the reflectance slope and a scaled surface leaf liquid water absorption spectrum [0 vary. Figure 4 shows the fit between [hc AVIRIS measured and the NLLSSF spectrum for the 940 water vapor absorption over the green grass target in the Jasper Ridge AVIRIS data. Over vegetated targets leaf water absorption, in this spectral region, most bc compensated in the algorithm to avoid incorrect estimation the atmospheric water vapor. When applied to the entire AVIRIS Jasper Ridge data set a range in atmospheric water vapor from 9 to 22 precipitable millimeters of atmospheric water vapor was mapped.

For a future spaceborne sensor, a set of four 20 nm spectral bands placed at 870, 940, 980 and 1050 nm could be used to directly estimate atmospheric waler vapor. The 980 nm band would be used to compensate for leaf liquid water absorption. This assessment of water vapor would be used to compensate for water vapor absorption in all spectral bands. The 870, 940 and 1050 nm sensor bands might have 100 m spatial resolution, while specifying the 980 nm band at 30 m resolution would provide a leaf water parameter for remote sensing of the land surface.

3.() CIRRUS CLOUDS

The presence of cirrus clouds will affect the radiance an iving at a spaceborne sensor in this spectral region. and yet such cloud in fluence may be diffi cult to detect. A spectral band placed in the strong atmospheric water vapor absorption region will return signal to a spaceborne sensor only when high albedo targets such as cir rus clouds are present in the upper atmosphere. Based on this hypothesis, a cirrus cloud detection algorithm has been tested using the 1380 nm spectral channel of AVIRIS (Gao and Goetz, 1993). On extremely low humidity days or at high altitudes some surface reflected signal may be measured at 1380 nm. Therefore, a 20 to 40 nm band in the stronger waler vapor absorption regions at 1880 or 2500 nm is proposed for the detection and mapping of cirrus clouds in an advanced land remote sensing system.

4.() PRESSURE ELEVATION

In order to compensate for atmospheric absorption due to well mixed atmospheric gases and the effect of atmospheric molecular scattering, an estimate of the surface pressure elevation is required. An algorithm has been developed to estimate the surface pressure elevation (Green et al, 1991 b and Green et al., 1993) from the AVIRIS measured radiance. This algorithm assesses the strength of the 760 nm oxygen absorption band measured in the AVIRIS data. The oxygen band strength is calibrated to surface pressure elevation using the oxygen band mode] in the MODTRAN2 radiative transfer code. Parameters constraining the pressure elevation. the reflectance magnitude and the reflectance slope in the 760 nm spectral region arc allowed to vary in the fit. When applied to the entire Jasper Ridge AVIRIS data set, pressure elevations were calculated that ranged from O m towards the San Francisco Bay to 800 rn in the mountains on the peninsula. These estimates are consistent v., ith the topography of the region.

Spectral bands 1() nm wide placed at 745, 760 and 775 nm might be used to calculate surface pressure elevation in future land remote sensing systems. An alternate set of 20 nrn wide hands at 2040," 2060 and 2080" nm measuring the carbon dioxide absorption in the atmosphere might be employed as well for the estimation of surface pressure elevation. In this 2000 to 2100 nm spectral region compensation for water vapor absorption will be required. The spatial field of view of the bands could be on the order of 100" m and still provide appropriate information for compensation of the atmosphere.

5.() AEROSOL OPTICAL DEPTH

Under low visibility conditions the radiance scattered from atmospheric aerosols may comprise a significant proportion of the total radiance reaching a spaceborne sensor, As an example, a plot showing the aerosol-scattered radiance contribution to the total radiance from a 0.25 reflectance surface with a 5 km visibility rural atmosphere visibility is given in Figure 5.

For AVIRIS, a nonlinear least square spectral fitting (NLLSSF) algorithm has been developed to estimate the aerosol optical depth directly from the measured radiance. This algorithm optimizes the fit between the AVIRIS measured radiance and a MODTRAN2 modeled radiance with the aerosol optical depth as the primary fitting parameter. Parameters modeling the reflectance magnitude, the reflectance slope and leaf chlorophyll absorption arc also includ ccl in the fitting algorithm. For the Jasper Ridge data an assumption of aerosol type was required. The MODTRAN2 rural aerosol model was used, Aerosol optical depths at 500 nm were calculated for the entire Jasper Ridge AVIRIS data set that ranged from 0.27 in the peninsula mountains to 0.53 near the San Francisco bay.

Several spectral bands in the 400 to 600 nm spectral region might be used in an advanced spaceborne sensor to estimate aerosol optical depth. However, additional research is required for validation of this approach.

6,() REFLECTANCE CALCULATION

Calculation of" surface spectral reflectance from the total upwelling radiance measured by AVIRIS using a radiative transfer code has been pursued since [he. flights of AVIRIS in 1989 (Green, et al. 1990, Green, et al. 1991b, Green et al. 1993). Using the water vapor, pressure elevation and aerosol optical depth estimates derived in the previous algorithms, the two way transmitted radiance and atmospheric path radiance spectrum arc calculated for each spatial element with MODTRAN2. Computer look up tables arc used to accelerate these calculations. With these determined parameters the surface reflectance is calculated directly. Figure 6 shows the calculated reflectance spectra for the green vegetation target. The total measured radiance for this target is shown in Figure 2. Inspection of this calculated reflectance spectrum shows compensation for the solar irradiance, atmospheric absorption and atmospherically scattered radiance. In future, similar algorithms may allow calcualtion of reflectance from data measured by an advanced spaceborne optical sensor, provided bands arc included specifically for characterization of the necessary atmospheric parameters.

7.0 CONCLUSION

Algorithms are described that allow estimation of the absorption and scattering characteristics of the atmosphere from sensor measured radiance. With estimation of these atmospheric parameters, apparent surface reflectance may be calculated from the measured radiance. The algorithms described usc the MODTRAN2 radiative transfer code for modeling the absorption and scattering properties of the atmosphere. To analyze these senor measured data with a radiative transfer code. such as MODTRAN2, an accurate spectral, radiometric and geometric calibration of the data is required.

As these algorithms arc further validated, they will offer an approach to provide apparent surface reflectance data directly to the users of the AVIRIS data. With appropriate bands in an advanced land remote sensing system, an equivalent set of algorithms could be applied routinely to the measured data to compensate for effects in the data caused by variation in the absorption and scattering of the terrestrial atmosphere and for attenuation by sub visual cirrus clouds.

8.0 ACKNOWLEDGMENTS

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9.0 REFERENCES

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10.() FIGURES

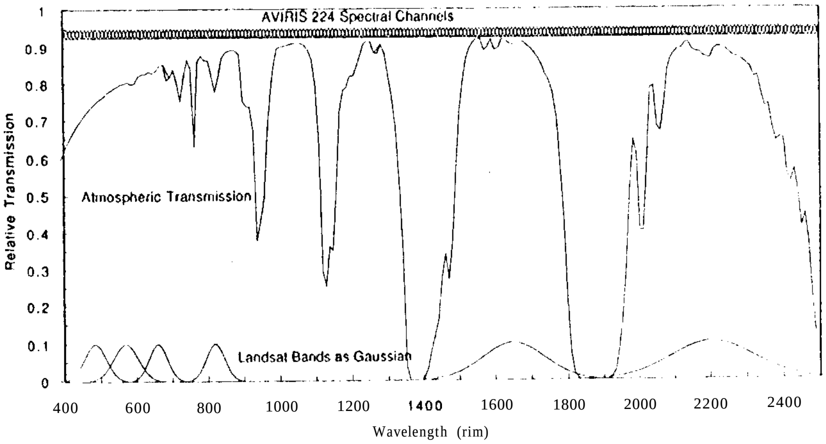

Figure 1. AVI RIS spectral channels plotted with Thematic Mapper bands and a typical [transmission spectrum of the terrestrial atmosphere.

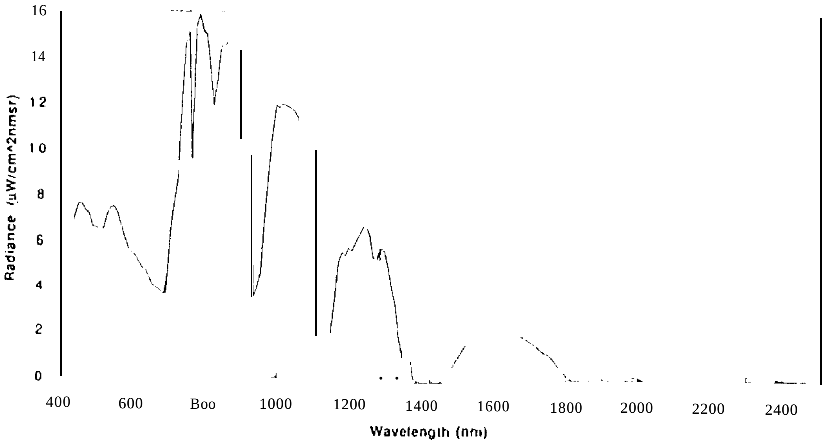

Figure 2, AVIRIS measured upwelling radiance spectrum of a green grass target at Jasper Ridge, CA.

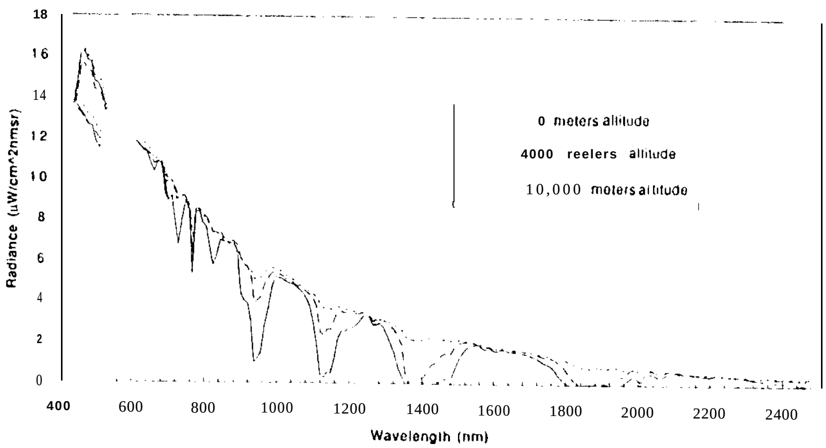

Figure 3. Influence of water vapor absorption on sensor measured radiance in the terrestrial atmosphere.

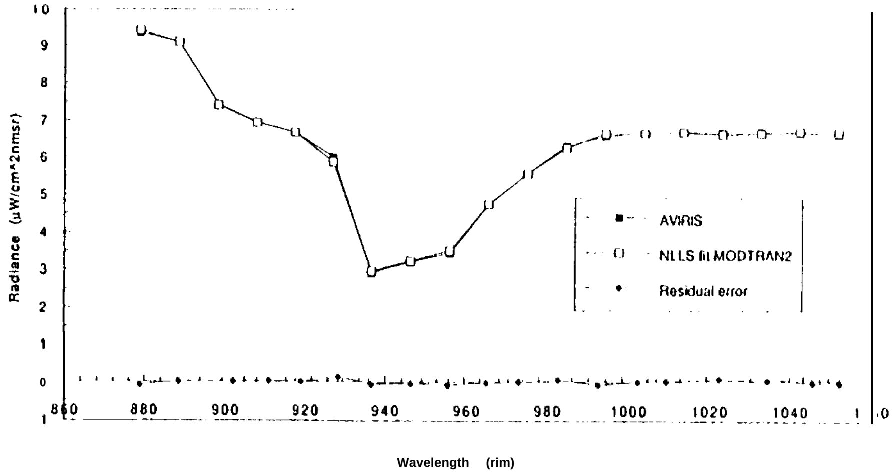

Figure 4. Fit and residual between an AVIRIS measured radiance spectrum and a NLLSSF spectrum for estimation of total path atmospheric water vapor.

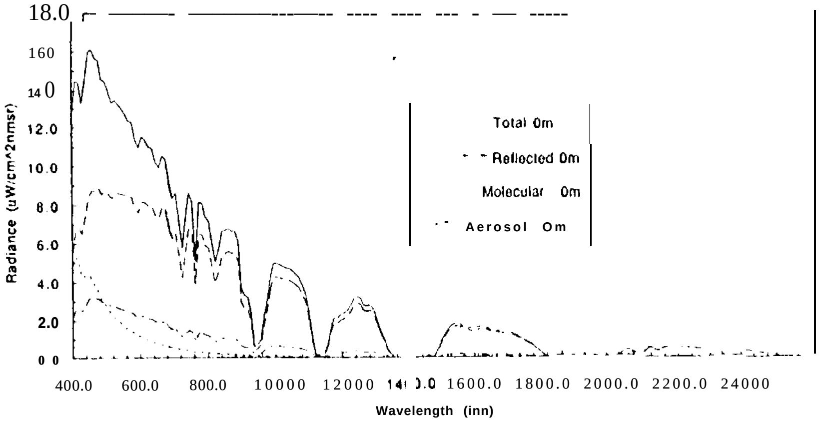

Figure 5. A plot showing the MODTRAN2a modeled total radiance for a 25 percent reflectance target at 0 m elevation with a 5 km visibility atmosphere. Also show arc the reflected, molecular scattered and aerosol scattered radiance components of the total upwelling radiance.

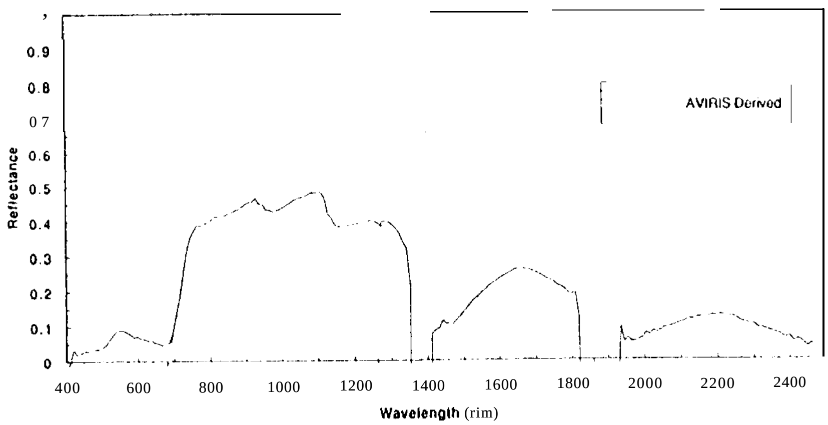

Figure 6. Calculated apparent surface reflectance for the green grass target.

11.0 PLATES

Plate 1. AVIRIS color image cube of Mount Shasta in northern California. The front panel is a color composite of three of the AVIRIS spectral channels. The side panels are projections of the 224 spectral channels acquired for each of the 614 by 512 spatial elements measured in a single AVIRIS scene.